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NUTRIENTS IN MUDDY CREEK
AND
WASTEWATER DRAINS OF THE GREENFIELDS IRRIGATION DISTRICT

prepared for

The Muddy Creek Special Water Quality Project

by

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SUMMARY

A study of major irrigation drains and dryland tributaries to Muddy Creek near Great Falls was conducted from April to October 1980. Nutrients in Muddy Creek, drains and tributaries were measured every two weeks. Dryland tributaries were minor sources of nutrients during the irrigation season. Drains contributed a large percentage, but not all, of the nitrate in Muddy Creek. The average nitrate concentration in the drains was intermediate between that in Muddy Creek and that in groundwater wells on the Greenfields Irrigation District. Presumably, groundwater discharge from the District was also a significant source of nitrate in Muddy Creek. Phosphorus, not nitrogen, was the nutrient limiting algae growth in Muddy Creek. The average phosphorus concentration in Muddy Creek was slightly larger than that in the drains. A strong positive correlation was found between phosphorus and suspended sediment, supporting an assumption that excess flows and accelerated channel erosion in Muddy Creek account for the somewhat larger phosphorus concentrations instream.

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INTRODUCTION

A study of nitrogen and phosphorus in Muddy Creek and in three surface irrigation drains and three dryland tributaries to Muddy Creek near Vaughn, Montana (Fig. 1) was conducted between April and October 1980.

Muddy Creek is located on the high plains just east of the front range of the Rocky Mountains. It is a tributary of the Sun River in an area of highly erosive clay soils.

The Greenfields Irrigation District occupies a large part of the Muddy Creek drainage (Fig. 1). The District imports a large amount of water from the upper Sun River. Waste water and return flows from the District are discharged to Muddy Creek, thereby exceeding the stream's natural flow. This hydraulic overloading of the Muddy Creek channel has caused severe bank erosion and downstream sedimentation (Systems Technology, 1979).

Irrigation return flows are frequently rich in plant nutrients. Nitrogen and phosphorus are the two nutrients that most commonly stimulate the growth of algae in lakes and streams. Too much of these nutrients in the water will cause nuisance "blooms" of algae, like infestations of noxious weeds on land.

Only certain forms of nitrogen and phosphorus are readily available to algae: nitrogen as nitrate (NO_3), nitrite (NO_2) and ammonia (NH_3 plus NH_4), and phosphorus as orthophosphate (PO_4)[1]. The sum of the three nitrogen forms is called total soluble inorganic nitrogen or TSIN. The sum of all phosphorus forms is called total phosphorus or TP.

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[1] Henceforth in this report, "nitrate" will mean nitrate plus nitrite. By convention, all nutrient concentrations are expressed in terms of the constituent element. For example, a nitrate concentration of 5.38 mg/l (milligrams per liter) means there was that amount of nitrogen present in both the nitrate (NO_3) and nitrite (NO_2) radicals. The portions of these radicals composed of oxygen are not included.

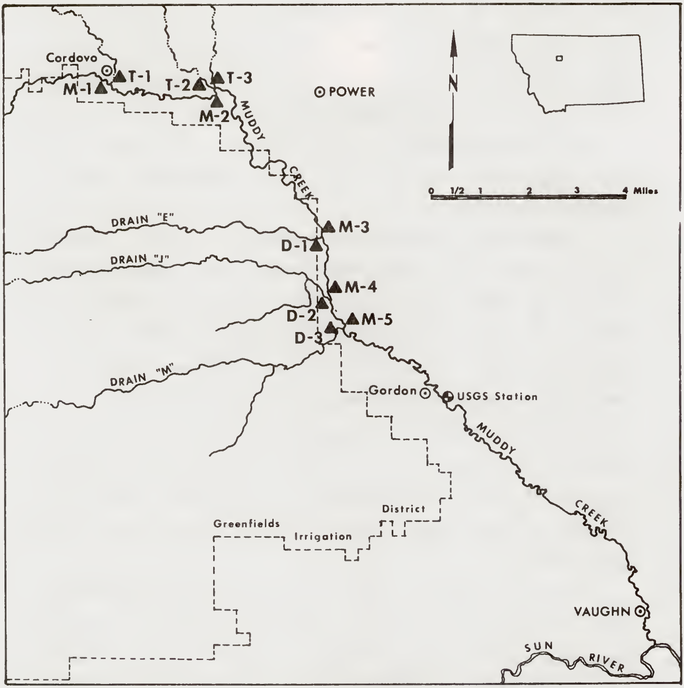

Figure 1. Map showing study area and water quality stations.

Muddy Creek nutrient data collected by the U.S. Geological Survey (USGS) and the Bureau of Reclamation were summarized by Systems Technology (1979). The average nitrate concentration at the USGS streamflow gaging station near Vaughn (Fig. 1) was 2.15 mg/l (milligrams per liter). The average total phosphorus (TP) concentration at the same station was 0.07 mg/l and the maximum concentration was 0.26 mg/l. TSIN concentrations exceeding 1.0 mg/l and TP concentrations exceeding 0.1 mg/l may cause nuisance growths of algae in running waters (U. S. Environmental Protection Agency, 1981).

Surplus flows and plant nutrients in Muddy Creek probably come from the Greenfields Irrigation District to the south and west of Muddy Creek (Fig. 1), but it is not known whether most nutrients enter the stream in groundwater or in surface irrigation drainage (Systems Technology, 1979).

Nitrate concentrations in wells on the District average 5.42 mg/l, which is four times the average concentration in groundwaters used as public water supplies in Montana (Walther, 1981) and more than twice the average concentration in Muddy Creek. Nutrient concentrations in surface drains and dryland tributaries discharging to Muddy Creek are the subject of this report.

The principal objective of this study was to demonstrate that surface drains from the Greenfields Irrigation District contribute more nutrients to Muddy Creek than do dryland tributaries. A second objective was to determine whether groundwaters from the Greenfields Irrigation District are a significant source of nutrients in Muddy Creek.

STUDY DESIGN

Eleven stations (Fig. 1) were monitored from April 9 to October 22, 1980:

D-1	Drain E at mouth
D-2	Drain J at mouth
D-3	Drain M at mouth
M-1	Muddy Creek at Cordova upstream from dryland tributary 1
M-2	Muddy Creek upstream from dryland tributaries 2 and 3
M-3	Muddy Creek upstream from Drain E
M-4	Muddy Creek upstream from Drain J
M-5	Muddy Creek upstream from Drain M
T-1	Dryland tributary 1
T-2	Dryland tributary 2
T-3	Dryland tributary 3

Flow, nitrate, ammonia, orthophosphate, total phosphorus and total suspended sediment (TSS) were measured every two weeks.

METHODS

Streamflow

Accurate measurements of streamflow are necessary for calculating loads of suspended and dissolved materials (including nutrients) carried by streams. Flows reported for all stations are instantaneous. Methods approved by the USGS (U.S. Geological Survey, 1977) were used for collecting streamflow data.

Nutrients

Unfiltered grab samples of nutrients were collected, preserved and analyzed following methods prescribed by the U. S. Environmental Protection Agency (1979). Analyses were performed by the Chemistry Laboratory Bureau of the Department of Health and Environmental Sciences in Helena.

Total Suspended Sediment

Total suspended sediment (TSS) is a measure of the amount of particulate material suspended in the water column. In the Muddy Creek drainage this material is mostly inorganic, consisting of sand, silt, and clay particles. Sediment is important as a vehicle for transporting phosphorus and because of its degrading effects on water quality and aquatic life.

TSS samples were collected according to the equal-width increment method (U. S. Geological Survey, 1977) using a depth-integrating type DH-48 sampler with a 0.25-inch orifice. Samples were analyzed at the Chemistry Laboratory Bureau of the Department of Health and Environmental Sciences by the gravimetric method (U. S. Environmental Protection Agency, 1979).

Load

Load is an estimate of the cumulative pollution burden of dissolved or suspended material, expressed in units of pounds or tons per day, that a stream transports over a given period of time. This estimate is based on instantaneous measurements of flow and pollutant concentration.

Correlation Analyses

The correlation coefficient (r) indicates the degree to which change in one variable is related to change in another variable. The correlation coefficient may range from -1 to +1. No relation exists if the coefficient equals 0, whereas a perfect relationship exists if the coefficient equals -1 or +1. A probability level of 5 percent or less indicates there is a better than 95 percent chance that a non-zero correlation coefficient exists between the two variables. Correlation analysis is not a valid basis for determining cause and effect relationships between an independent variable and a dependent variable; it only indicates whether the variables vary together, either directly or indirectly.

RESULTS

Streamflow

Mean flows in Muddy Creek increased downstream (Table 1). Drain E contributed 57 percent of the increased flow in the segment between Drains E and J. Drain J contributed 98 percent of the increased flow in the segment between Drains J and M. Flows in the dryland tributaries were very small: less than 1 cubic foot per second (cfs), except on two occasions when they were 1.5 cfs and 3.6 cfs.

Table 1. --Instantaneous streamflows in the Muddy Creek drainage from April to October 1980 (cfs = cubic feet per second)

Station	Total of biweekly instantaneous streamflow measurements (cfs)	Number of Measurements	Mean instantaneous streamflow (cfs)
M-1	369	14	26
M-2	571	15	38
M-3	718	15	48
D-1 (Drain E)	96	15	6
M-4	887	15	59
D-2 (Drain J)	514	15	34
M-5	1413	15	94
D-3 (Drain M)	456	15	30

Nutrients

Mean nitrate concentrations in the different types of water from the study area are presented in Table 2. On the average, nitrate concentrations were largest in the wells studied by Walther (1981) and smallest in the drains. Mean nitrate concentrations in Muddy Creek were intermediate between those of wells and drains. Mean concentrations of nitrate in the three types of water were significantly different from one another at a probability level of 1 percent. Seasonal changes in the mean concentrations of nitrate in wells, drains, and Muddy Creek are illustrated in Fig. 2.

Table 2. --Nitrate concentrations in samples from wells, drains and Muddy Creek (mg/l).

Water	Number of samples	Mean value (mg/l)	Standard Deviation* (mg/l)
Wells (Walther,1981)	400	5.38	5.82
Drains	45	0.96	0.51
Muddy Creek	74	2.02	1.36

* Standard deviation is a measure of variability in the recorded values about the sample mean.

Frequent low flows permitted collection of only nine samples from the dryland tributaries. The mean concentration of nitrate in these nine samples was 1.15 mg/l and values ranged from less than 0.01 mg/l to 6.00 mg/l. Total nitrate load to Muddy Creek from the dryland tributaries was less than 1 percent of the load from the drains.

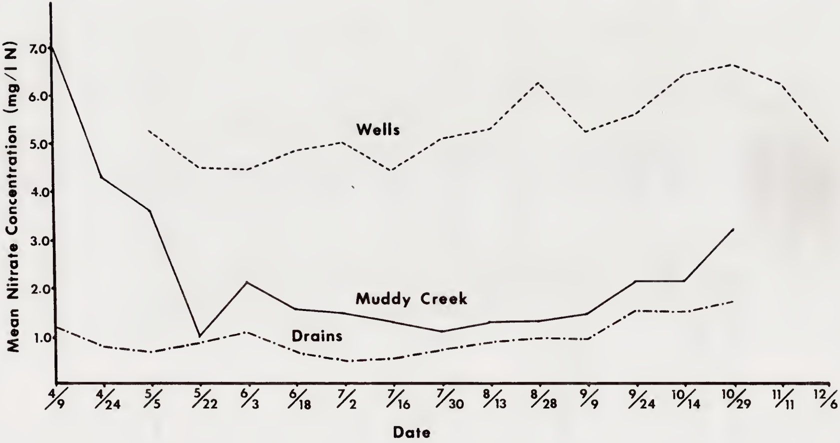

Figure 2.--Seasonal changes in mean nitrate concentrations (mg/l) in wells, drains, and Muddy Creek for 1980. Well data from Walther (1981).

Mean nitrate values for the Muddy Creek and drain stations are presented in Table 3. Student's "t" tests were applied to paired station means to determine whether they were significantly different at a probability level of 1 percent.

Mean nitrate concentrations at the five Muddy Creek stations were not significantly different from one another. The mean nitrate concentration in Drain E was significantly larger than the mean nitrate concentration in Drain M. No significant differences were found between the means of E and J drains or J and M drains. Similarly, no significant differences were found when the

Table 3. --Nitrate concentrations at the five Muddy Creek stations and the three drains (mg/l)

Station	Number of samples	Mean value (mg/l)	Standard Deviation (mg/l)
M-1	14	1.81	0.56
M-2	15	1.86	1.01
M-3	15	2.28	1.86
D-1 (Drain E)	15	1.30	0.47
M-4	15	2.29	1.65
D-2 (Drain J)	15	0.89	0.52
M-5	15	1.86	1.38
D-3 (Drain M)	15	0.70	0.34

* Standard deviation is a measure of variability in the recorded values about the sample mean.

mean concentration of nitrate in each drain was compared with the mean concentration of nitrate in Muddy Creek immediately above the drain. However, nitrate concentrations in the drains were frequently smaller than those in Muddy Creek immediately above the drains (Table 4).

Table 4. --Nitrate concentrations in drains relative to nitrate concentrations in Muddy Creek immediately above the drains (percent frequency)

Drain	Concentrations smaller than in Muddy Creek	Concentrations larger than in Muddy Creek	Concentrations equal
Drain E	66	27	7
Drain J	93	7	0
Drain M	100	0	0

The total nitrate load for each station over all sampling dates was calculated by summing the estimated daily loads for each sampling date. The estimated daily load on each sampling date was derived from a single pair of instantaneous flow and nitrate measurements projected over a 24-hour period. Load values at the various stations do not necessarily represent the same body or "slug" of water.

Nitrate loads increased downstream in Muddy Creek (Table 5). From Cordova to Drain E the mean daily nitrate pickup was 0.11 tons. Between Drain E and Drain M it was 0.12 tons. Mean daily nitrate pickup per mile between Cordova and Drain E was 0.01 tons, which increased to 0.05 tons per mile between Drain E and Drain M.

Table 5. --Daily nitrate loads in the Muddy Creek drainage from April to October 1980 (tons)

Station	Total of daily loads measured biweekly (tons)	Number of Sample dates	Mean daily load (tons)
M-1	1.74	14	0.12
M-2	2.73	15	0.18
M-3	3.50	15	0.23
D-1 (Drain E)	0.36	15	0.02
M-4	4.40	15	0.29
D-2 (Drain J)	0.85	15	0.06
M-5	5.27	15	0.35
D-3 (Drain M)	0.76	15	0.05

Drain E contributed 40 percent of the nitrate pickup in the segment between Drains E and J, while other sources contributed 60 percent. Drain J contributed 98 percent of the nitrate pickup in the segment between Drains J and M, while other sources contributed 2 percent. Relative nitrate contributions by both drains were larger after July 15 than before this date.

The mean ammonia concentration among all samples was 0.02 mg/l. Individual values ranged from less than 0.01 mg/l to 0.25 mg/l. Ammonia accounted for only 2.6 percent of the average total soluble inorganic nitrogen (TSIN) value. On two occasions, once in each dryland tributary, ammonia accounted for more than 50 percent of the TSIN.

Orthophosphate and total phosphorus concentrations in the drains averaged 0.08 mg/l and 0.15 mg/l, respectively. Orthophosphate concentrations ranged from less than 0.01 mg/l to 0.54 mg/l and total phosphorus concentrations ranged from 0.01 mg/l to 0.91 mg/l. Concentrations of orthophosphate and total phosphorus at the five Muddy Creek stations averaged 0.11 mg/l and 0.16 mg/l, respectively. Individual values ranged from less than 0.01 mg/l to 0.55 mg/l for orthophosphate and from less than 0.01 mg/l to 0.91 mg/l for total phosphorus.

Total Suspended Sediment

Total suspended sediment (TSS) loads increased downstream in Muddy Creek (Table 6). Each of the drains increased the TSS load in Muddy Creek by an average of 23 percent. Mean concentrations of TSS were significantly larger in Muddy Creek upstream of the drains than in the drains themselves. The mean TSS concentration in Muddy Creek was 184 mg/l, whereas in the drains it was 101 mg/l.

Table 6. --Daily sediment loads in the Muddy Creek drainage from April to October 1980 (tons)

Stations	Total of daily loads measured biweekly (tons)	Number of sample dates	Mean daily load (tons)
M-1	147.4	14	10.5
M-2	367.2	14	26.2
M-3	404.0	14	28.9
D-1 (Drain E)	18.7	14	1.3
M-4	475.6	14	34.0
D-2 (Drain J)	156.0	14	11.1
M-5	659.7	14	47.1
D-3 (Drain M)	199.0	14	14.2

Correlation Analyses

Correlation coefficients were calculated between TSS, flow and nutrient concentrations in drains and in Muddy Creek (Table 7). Large positive correlations between TSS and orthophosphate and between TSS and total phosphorus were significant at a probability level of 1 percent. A small positive correlation between TSS and flow in Muddy Creek was significant at a probability level of 5 percent. The corresponding correlation in the drains was negative and not significant at 5 percent. Negative correlations between TSIN and flow and between TSIN and TSS were significant at a probability level of 1 percent in the drains but not significant at a level of 5 percent in Muddy Creek. Figure 3 illustrates the relationship between TSIN and flow in each of the drains.

Table 7.--Correlations between streamflow, total suspended sediment, and nutrients in Muddy Creek and the drains

Water Source	Variables	Number of Observation Pairs	Correlation Coefficient (r)	Level of Probability
Muddy Creek	TSS, orthophosphate	70	0.78	1%
	TSS, total phosphorus	70	0.85	1%
	TSS, TSIN	70	-0.15	greater than 5%
	streamflow, TSIN	74	-0.19	greater than 5%
	streamflow, TSS	70	0.25	5%
Drains	TSS, orthophosphate	42	0.52	1%
	TSS, total phosphorus	42	0.64	1%
	TSS, TSIN	42	-0.43	1%
	streamflow, TSIN	45	-0.52	1%
	streamflow, TSS	42	-0.26	greater than 5%

TSS = total suspended sediment; TSIN = total soluble inorganic nitrogen

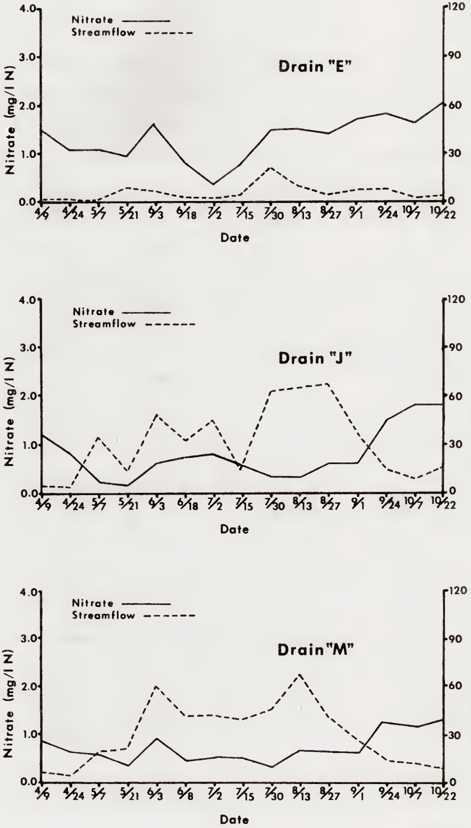

Figure 3.--Seasonal changes in streamflow (cfs) and nitrate concentrations (mg/l) in drains E, J, and M for 1980.

DISCUSSION

Nitrate is the primary form of inorganic nitrogen in Muddy Creek and in Drains E, J, and M. Possible sources of nitrate include fertilizer, manure, rainfall, marine shales, and decomposition of soil organic matter (Thompson and Custer, 1976). The average nitrate concentration in Muddy Creek was 15 times larger than the average for Montana surface waters (Botz and Pedersen, 1976).

The Greenfields Irrigation District is the most hydrologically-active area in the Muddy Creek drainage and the major contributor of nitrate. While tributaries from the dryland part of the drainage may contribute large concentrations of nitrate, flows generally are small and short-lived. Nitrate loadings from these sources are negligible.

Nitrate concentrations in Muddy Creek were between those found in the drains and those found in the wells studied by Walther (1981). This is probably a function of mixing between high-nitrate groundwater and lower-nitrate drain wastewater.

Nitrate concentrations were smallest in the drains presumably because conditions were more favorable here for algal production and nitrate consumption. Similarly, algal production was smaller, nitrate consumption was reduced, and nitrate concentrations remained higher in Muddy Creek because of the poor growing conditions for algae. Muddy Creek has a more unstable bottom and more turbid waters than the drains. The largest concentrations of nitrate were observed in the groundwater (wells) where very little nitrogen consumption takes place.

Nitrate loading was variable within and between segments of Muddy Creek. In the segment below Drain E, for example, nitrate loading in July shifted from mostly groundwater to mostly waste drains. In October the load source shifted back to predominantly groundwater. An increase in surface return flows beginning in mid-July may be the reason for this shift. The same shift did not occur in the segment below Drain J. Drain J drains a larger area and carries more wastewater than Drain E. Thus, Drain J probably is influenced more by surface return flows than is Drain E.

Flow and TSIN in the drains were negatively correlated at a probability level of 1 percent, although the correlation was not strong. Base flows in the drains were evidently sustained by high-nitrate groundwater whereas larger flows originated as surface return, unused wastewater, and precipitation, all of which have lower concentrations of nitrate. This probably accounts for the inverse relationship between flow and TSIN.

Considering the ratio of mean TSIN to mean orthophosphate concentration (about 10 to 1) and the ratio of these nutrients preferred by most algae (7 to 1), phosphorus was the limiting nutrient in Muddy Creek (Zison and others, 1977). Concentrations of phosphorus in the drains averaged slightly smaller than those in Muddy Creek. Phosphorus originates mostly from overland runoff and stream channel erosion; it is not readily transported through soils. Excess flows in Muddy Creek and accelerated channel erosion probably account for the slightly larger phosphorus concentrations instream.

Unstable bottoms, scouring sediment, and light-occluding turbidity are probably more effective at preventing nuisance growths of algae in Muddy Creek than limiting but large concentrations of phosphorus, which were often more than enough to cause algae problems given ideal growing conditions and ambient nitrate concentrations.

REFERENCES CITED

Botz, M. K., and R. Pedersen. 1976. Summary of water quality criteria. Water Quality Bureau, Montana Department of Health and Environmental Sciences, Helena.

Systems Technology. 1979. Muddy Creek special water quality project. Systems Technology, Inc., Helena.

Thompson, G. R., and S. G. Custer. 1976. Shallow ground-water salinization in dryland-farm areas of Montana. Report No. 79, Montana University Joint Water Resources Research Center, Bozeman.

U. S. Environmental Protection Agency. 1979. Methods for chemical analysis of water and wastes. EPA-600/4-79-020. Environmental Monitoring and Support Laboratory, Cincinnati.

U. S. Environmental Protection Agency. 1981. Water quality criteria matrix. Region VIII, Denver.

U. S. Geological Survey. 1977. National handbook of recommended methods for water-data acquisition. Office of Water Data Coordination, Reston.

Walther, K. C. 1981. Nitrates in wells of the Greenfields Irrigation District, Fairfield, Montana. WQB Report No. 81-1. Water Quality Bureau, Montana Department of Health and Environmental Sciences, Helena.

Zison, S. W., K. F. Haven and W. B. Mills. 1977. Water quality assessment: A screening method for nondesignated 208 areas. EPA-600/9-77-023. U. S. Environmental Protection Agency, Environmental Research Laboratory, Athens.